3-D Resistivity Imaging of Single-Hole EM Data

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RESEARCH OBJECTIVES

Traditionally, electromagnetic (EM) induction logging has been widely used for directly measuring the formation conductivity surrounding uncased wells. Such a logging tool primarily consists of a magnetic dipole transmitter and a receiver in a coaxial configuration, in line with the borehole axis. As a result of this cylindrically symmetric nature of source and receiver, induction logging data offer no information about the 3-D conductivity distribution in the vicinity of the borehole. We can only characterize the 3-D conductivity structure surrounding a borehole if we can acquire multiple components of the magnetic fields resulting from various source polarizations. However, 3-D interpretations using such single-hole EM data are difficult because of the richness and complexity of the data and the very large number of discretized conductivity elements needed to construct a realistic earth model. Taking advantage of the computing efficiency of an algorithm based on a modified extended Born approximation (MEBA), we have developed an algorithm for simulating and interpreting EM data acquired in a single-hole environment.

APPROACH

Successful 3-D interpretation of geophysical EM single-hole data depends on the efficiency of a fast forward simulation as well as a sound inversion strategy. For EM simulations, scattered magnetic field at observing locations can be calculated, provided the total electric field in a confined conductivity inhomogeneity is known. This electric field can be derived using the integral equation method. However, this method quickly becomes impractical if the number of discretized cells making up the anomalous region exceeds a certain limit. Based on an approximation approach, the MEBA technique avoids this problem by calculating the total electric field in the electrical conductivity anomaly without solving any huge matrix equation. This methodology also provides an efficient way to calculate the Jacobian matrix for a 3-D inversion, which is based on a least-squares criteria and uses a conjugate gradient method for solving the system matrix equation.

ACCOMPLISHMENTS

We have verified the algorithm with simulation data. A set of single-hole data collected at a site for a pilot CO_2 injection project in southern California was used for inversion. The inverted conductivity structure around a borehole is displayed in Figure 1. Electrical conductivity variation within 8 m around the borehole is clearly indicated—this could never have been achieved with logging data. The results conform well to induction logging data and a crosshole section.

SIGNIFICANCE OF FINDINGS

With multicomponent magnetic data, 3-D interpretation of geophysical EM single-hole data is now practical on PC-based computing platforms. Weightings of the data must be carefully selected because of the strong transmitter-receiver coupling between the transmitting and receiving units for coaxial and co-planar components.

RELATED PUBLICATION

Tseng, H.-W., K.H. Lee, and A. Becker, 3-D interpretation of electromagnetic data using a modified extended Born approximation. Geophysics, 68, 127–137, 2003.

ACKNOWLEDGMENTS

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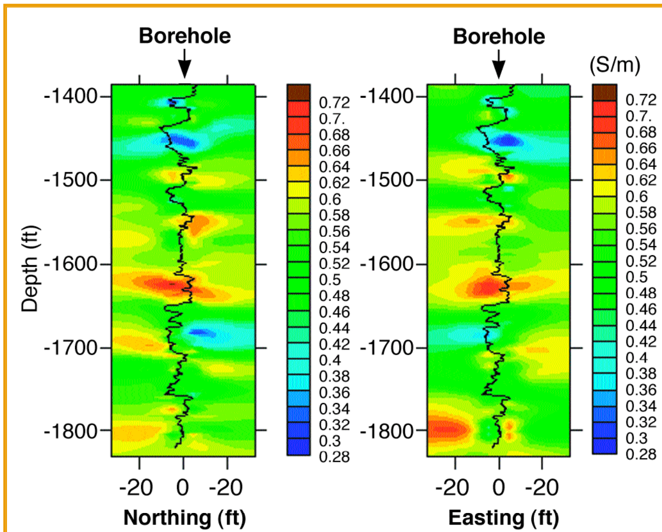

Figure 1. Inverted conductivity structure centered at a borehole in the CO_2 injection project site. Transmitter-receiver separation was 5 m; transmitter operating frequency was 6 kHz. Because of a vertical source, all three magnetic-field components were used for the inversion. The induction logging data is also displayed at the center of each panel for comparison.